PATENT SPECIFICATION

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COMPLETE SPECIFICATION

Improvements in or relating to Electric Cables for High Frequency

We, STANDARD TELEPHONES AND CABLES LIMITED, a British Company, of Connaught House, 63, Aldwych, London, W.C.2, England, do hereby declare the nature of this invention and in what manner the same is to be performed, to be particularly described and ascertained in and by the following statement:—

The present invention relates to electric cables of the coaxial type for high frequency purposes.

It is known in such cables to form the outer conductor with corrugations in order to give flexibility to the cable. The problem of flexibility becomes acute in the manufacture and handling of cables of large diameter. Before laying the cables are normally coiled upon drums and with coaxial cables employing tubular copper outer conductors the size of drum required in order that the conductor may not be damaged when the cable is wrapped around the drum may well become excessive for cable diameters of the order of two and a half centimeters or more. Corrugations in the outer conductor may overcome the difficulty but at the cost of increasing the attenuation of the cable.

It is an object of the present invention to provide a high frequency cable in which the necessary flexibility is attained by means of corrugations which do not unduly increase the attenuation of the cable.

The invention will be understood from the following discussion of the principles involved, having reference to the accompanying drawings in which:—

Fig. 1 is a diagrammatic drawing of part of a cable bent round a cable drum.

Fig. 2 is a diagrammatic drawing of a length of the outer conductor of a cable according to the present invention, but with the dimensions considerably exaggerated for the sake of clarity.

A particular embodiment of the invention will hereinafter be described with reference to Fig. 3 which shews a perspective view, partly sectionalised, of a length of cable according to the present invention but, again for the sake of clarity, with some exaggeration of the relative dimensions.

When a cable of external diameter D is coiled on to a drum or cylinder of diameter B, the curvature imparted to the cable changes the relative lengths of what become the inner and outer surfaces of the cable on the drum. If as shown in Fig. 1, l_1 is the length of the outer surface, l_2 the length along the axis of the cable and l_3 the length along the inner surface of the cable on the drum, then the bending operation may do one of three things, as follows.

The length l_2 may be the same as it was when the cable was straight. This will result in l_1 becoming longer and l_3 becoming shorter by amounts approximately as given in the following expressions bearing in mind that D is small compared with B.

$$l_1 = l_2\left(1 + \frac{D}{B}\right)$$

$$l_3 = l_2\left(1 + \frac{D}{B}\right)$$

The length l_3 may be the same as it was when the cable was straight, then:—

$$l_1 = l_3\left(1 + \frac{2D}{B}\right)$$

$$l_2 = l_3\left(1 - \frac{D}{B}\right)$$

The length of l_1 may be same as it was when the cable was straight, then:—

$$l_2 = l_1\left(1 - \frac{D}{B}\right)$$

$$l_3 = l_1\left(1 - \frac{2D}{B}\right)$$

It is clear from this that for safety we have to take the worst of these, namely a possible stretching of the outer surface l_1 by an amount equal to $\frac{200D}{B}$ per cent. or a contraction of the inner surface of the same amount. This means that the outer tube of, for example, a coaxial cable of diameter D must be capable of changing its length by $\pm\frac{200D}{B}$ per cent. without damage to its structure if it is to be coiled or uncoiled onto or from a drum of diameter B.

Bending tests indicate that a coaxial core having a plain cylindrical outer tube of copper cannot be coiled without risk of damage to the outer tube onto a drum for which 200D/B is greater than 2, i.e. the diameter of the drum must be at least one hundred times the overall diameter of the outer tube.

For a coaxial core of large size, say for example 2.54 cm. external diameter, the drum diameter which conforms to the 2% requirement is B=100D=2.54 metres. As this is the diameter of the centre of the drum, for a normal length of cable the external diameter would amount to more than 3 metres. Drums of so large a diameter are inconvenient to handle and cause difficulties in transport.

We have therefore to solve the problem of making a coaxial core of say 2.54 cm. overall diameter and coiling it on the largest size drum that can conveniently be handled in a normal manner, and this may be taken as one having a minimum diameter of about 1.2 metres. The ratio B/D is therefore about 48. It is common in coiling cables on drums to use drums having a minimum diameter about fifty times as great as the overall diameter of the cable. For the present specification and appended claims the desirable B/D ratio has been set at 40 to provide a margin of safety. Thus the radius of curvature through which the cable is bent must be at least twenty times as great as the overall diameter of the outer conductor.

The actual ratio of 48 quoted above gives a value of approximately 4.2% for $\frac{200D}{B}$ for a cable of 2.54 cms. core diameter.

This change in length is too great for a plain cylindrical outer copper tube and the tube can only be given the necessary flexibility by corrugating it.

At first sight it would appear sufficient for the corrugations to increase the length of the copper tape in the outer tube by an amount equal to $\frac{200D}{B}$% i.e. 4.2% for the example under review, but if this is done the outer surface l_1, may have its corrugations completely removed by the stretching and on straightening the cable there is then a risk that the corrugations will not reform in an orderly manner.

A factor of safety must therefore be introduced and this is provided for by ensuring that the corrugations increase the copper tape length by twice $\frac{200D}{B}$ i.e. $\frac{400D}{B}$% or 8.5%.

It is desirable to avoid sharp bends in the corrugations and hence a sinusoidal profile is preferred for these. Referring now to Fig. 2 which represents the form —greatly exaggerated—of a longitudinal section of a tube of radius b with sinusoidal corrugations of amplitude c and wavelength λ, it can be shown that the length S taken along the sine curve through a complete wavelength is given by

$$\frac{S}{\lambda} = \frac{2}{\pi} \sec K(\alpha) \quad . \quad . \quad . \quad . \quad (1)$$

where $\tan \alpha = 2\pi\frac{c}{\lambda}$ and $K(\alpha)$ is the complete elliptical integral of the first kind, of modulus α.

Since the requirement stated above is that the increase in the length of the outer conductor must be 8.5% and this corresponds to $\frac{400D}{B}$% it is clear that to satisfy the requirements as to the flexibility of the cable we should make

$$\frac{S}{\lambda} = 1 + \frac{8b}{B} \quad . \quad . \quad . \quad . \quad (2)$$

remembering that $b = \frac{1}{2}D$.

Thus the ratio c/λ is now fixed; it remains to choose c or λ from other considerations. It is evident that the corrugations will increase the resistance of the cable compared to that with a cylindrical

outer conductor of the same mean diameter. The amplitude of the corrugations must, therefore, be made small. If on the other hand they be made too small compared with the thickness of the material it is evident that the conductor will not be able to " concertina."

The present invention provides a coaxial cable having a tubular outer conductor provided with continuous corrugations the dimensions of said corrugations in relation to the thickness and overall diameter of said conductor being such as to permit said cable to be bent so as to assume a curvature the radius of which is twenty times as great as the overall diameter of said outer conductor without damage to the structure of the cable either when so bent or when subsequently straightened and without unduly increasing the attenuation of the cable compared with that of a similar cable having a cylindrical outer conductor of the same mean diameter as said corrugated outer conductor.

According to another feature of the invention the depth of the corrugations is required to be not less than twice the thickness of the outer conductor material.

Preferably, as stated above, the corrugations are sinusoidal in profile as this is the simplest form of continuous corrugations not exhibiting sharp bends. When in the following description the term amplitude of the corrugations is used it is to be understood that the amplitude is half the depth of the corrugations.

In the preferred forms such as in Fig. 2 and the embodiment hereinafter to be described the corrugations lie perpendicularly to the axis of the cable.

In order to satisfy the extension requirement with an adequate margin of safety, for the numerical example given above the ratio $\frac{S}{\lambda}$ must equal 1.085 to allow for an extension of 8.5% in the copper tape length. Continuing with this example, from equation (1) it is found that the required value of $\frac{c}{\lambda}$ is 0.097. It can be shewn that, provided the amplitude c, of the corrugations be small compared with the mean internal diameter, $2b$ (Fig. 2), of the outer conductor, the increase in resistance caused by the corrugations is a function only of c—i.e. of $\frac{S}{\lambda}$—and is practically independent of $\frac{c}{b}$. For larger values of the ratio $\frac{c}{b}$ the increase in resistance is a function of both $\frac{c}{\lambda}$ and $\frac{c}{B}$ and becomes very much greater For this reason, according to another feature of the present invention, the amplitude of the corrugations should not exceed one per cent. of the mean internal diameter of the outer conductor, and, at the same time, in order to satisfy mechanical requirements as set by the elastic properties of the conductor—i.e. to enable it to " concertina " as explained above—the amplitude of the corrugation must not be less than the thickness of the outer conductor. The thickness t of the material of the outer conductor may be made as small as possible consistent with the required mechanical strength of the core and provided that t is greater than the " skin thickness " of the conductor corresponding to the range of frequencies it is desired to transmit. We have found that a satisfactory cable in which the attenuation constant is not increased by more than 3% and which may be bent round a practicable radius can thus be obtained provided the corrugations have an amplitude lying between $2b/100$ and t.

Summarising, in accordance with the present invention a preferred design for the outer conductor of a coaxial cable core of given diameter consists in choosing a convenient thickness t for the conductor material, choosing an amplitude c for the sinusoidal corrugations such that

$$2b/100>c>t$$

and determining λ from the ratio $c\lambda$ obtained as explained above from the required value of S/λ, the increased conductor surface length per wavelength of the corrugation.

To complete the design of the cable core it is necessary to determine the diameter, $2a$, of the inner conductor. We have found that the optimum diameter b/a is no longer 3.6 as it would be for a cylindrical outer conductor, but is greater than this. Depending upon the value of b, calculations indicate that for the range of values of c as given above, the optimum values of b/a lie between 3.7 and 4.0. The optima are not sharp, so that for an increase in attenuation constant of some 0.2% the ratio b/a may depart by $\pm 7\%$ from the optimum value and thereby allow a choice for the characteristic impedance within a range of $\pm 5\%$ of the value corresponding to the optimum b/a ratio.

The conductor may consist of one or more copper tapes folded to form the

conductor. The copper tape or tapes is or are preferably folded so as to be not quite a completely closed circle and the corrugations may be applied thereto during the final step of completing the circular form for example by a rolling-in process. The tape may be formed along each abutting edge with teeth which are made to overlap the co-operating edge, the teeth being formed to overlap on the outer side of the outer conductor as described, and claimed in British Specification No. 476,098.

A particular embodiment of the present invention is illustrated somewhat diagrammatically in Fig. 3 of the accompanying drawings.

The inner conductor 1 comprises a tube of copper tapes folded to shape and formed with teeth similarly to the outer conductor tapes, but designed to overlap on the inner side as described in the specifications accompanying applications Nos. 11723/45 and 14734/45 (Serial Nos. 650,425 and 650,426). This inner conductor may itself function as the outer conductor of a second coaxial cable core or may surround a plurality of conductors to be used for signalling circuits, power supplies for associated apparatus, or the like.

The inner conductor 1 is supported on discs 2 of low loss dielectric material. These discs are integral with sections of a tube 3 of the same material and are of one of the types described and claimed in the specifications accompanying Applications Nos. 30791/45 and 1831/46 (Serial No. 650,430).

The outer conductor 4 is applied about the insulating tube 3 in the manner described above. It should be noted that the corrugations have been exaggerated in the drawing for the sake of clarity, both the amplitude and the thickness being considerably in excess of the one per cent. of the mean diameter of the outer conductor.

The outer conductor is shewn bound with tapes 5 of copper and/or steel which may be two or more in number. The tapes. which would normally be considerably wider than a wavelength of the corrugations, are wound helically in the normal manner. On the other hand, should a cable according to the present invention be provided with corrugations lying helically with regard to the axis of the cable, it may be more convenient to provide a binding wire—or wires in the case of a multi-start helix 5—applied in the troughs of the corrugations. Neither in this case nor in that illustrated is the flexibility impaired by the binding.

By forming the corrugations according to the invention sufficient flexibility is imparted to the cable for winding upon cable drums of the usual size but the attenuation of the cable is not unduly increased; for the purposes of the present specification and the appended claims we consider an increase of attenuation of not more than 4% over that of a cable having a cylindrical outer conductor of the same mean diameter to be permissible. Moreover any irregularities in the corrugations and consequently in the attenuation produced by bending and unbending the cable are found to be decreased if the corrugations are initially shallow in accordance with this invention.

Having now particularly described and ascertained the nature of our said invention and in what manner the same is to be performed, we declare that what we claim is:—

1. Coaxial cable having a tubular outer conductor provided with continuous corrugations the dimensions of said corrugations in relation to the thickness and overall diameter of said conductor being such as to permit said cable to be bent so as to assume a curvature the radius of which is twenty times as great as the overall diameter of said outer conductor without damage to the structure of the cable either when so bent or when subsequently straightened and without unduly increasing the attenuation of the cable compared with that of a similar cable having a cylindrical outer conductor of the same mean diameter as said corrugated outer conductor.

2. Coaxial cable having a tubular outer conductor provided with continuous corrugations, the depth of said corrugations being not less than twice the thickness of the material of said conductors, the distance between adjacent corrugations being related to their depth in such a way as to permit said cable to be bent so as to assume a curvature the radius of which is twenty times as great as the overall diameter of said outer conductor without damage to the structure of the cable either when so bent or when subsequently straightened and without unduly increasing the attenuation of the cable compared with that of a similar cable having a cylindrical outer conductor of the same mean diameter as said corrugated outer conductor.

3. Coaxial cable according to claims 1 or 2 in which the profile of said corrugations along the axis of said cable is sinusoidal.

4. Coaxial cable according to claims 1. 2 or 3 in which said corrugations lie perpendicularly of the axis of said cable.

5. Coaxial cable according to claims 1

or 2 in which said corrugations are formed as a single or multiple start helix.

6. Coaxial cable having a tubular outer conductor provided with corrugations lying perpendicularly to the axis of said cable and having a sinusoidal profile in which the amplitude of the corrugation does not exceed one per cent. of the mean internal diameter of said outer conductor and is not less than the thickness of the material thereof, and in which the wavelength of said sinusoidal corrugations is such as to permit said cable being bent to a given curvature without damage to its structure either when so bent or after said curvature is removed.

7. Coaxial cable according to claims 3 or 6 in which the wavelength of said sinusoidal profile is chosen in relation to a given amplitude of the sinusoidal corrugations so that the ratio of the length of surface along said profile to the said wavelength exceeds unity by not less than four times the ratio of the mean radius of said outer conductor to the radius of said curvature.

8. Coaxial cable according to any preceding claim in which the ratio of the mean outer conductor diameter to the inner conductor diameter is made an optimum having regard to the propagation constants of such cables, said optimum having a value between 3.7 and 4.0.

9. Coaxial cable according to claim 8 modified in that the said ratio departs from the optimum value by not more than seven per cent., so as to provide a characteristic impedance differing from that corresponding to said optimum ratio by not more than five per cent. with an increase of attenuation of less than 0.2%.

10. Coaxial cable according to any preceding claim in which said inner conductor itself constitutes an outer conductor for a further cable contained within said coaxial cable.

11. Coaxial cable comprising an inner tubular conductor forming the outer conductor of a further electric cable, said inner tubular conductor being supported on disc insulators of low loss dielectric materials each disc insulator being integral with a section of a surrounding tubular insulating member of the same material, an outer tubular conductor applied above said tubular insulating member and being provided with sinusoidal corrugations lying perpendicularly to the axis of said cable, said corrugations having an amplitude c such that

$$\frac{2b}{100} > c > t$$

when b is the mean internal radius of said outer tubular conductor and t is the thickness of the material thereof, said corrugations also having a wavelength λ such that $\frac{S}{\lambda} = 1 + \frac{8b}{B}$ where B is twice the radius of maximum curvature through which said cable may be bent and S is the length along the surface of a complete wave of said sinusoidal profile, and two or more bindings of steel and/or copper tape wound helically about tubular outer conductor.

12. Coaxial cable according to claim 5 having a wire (or wires in the case of a multi-start helix) lying in the troughs of said corrugation and forming a binding for said outer conductor.

13. The coaxial cable herein described with reference to Fig. 3 of the accompanying drawing.

Dated this 4th day of September, A.D. 1946.

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[This Drawing is a reproduction of the Original on a reduced scale.]

FIG.1.

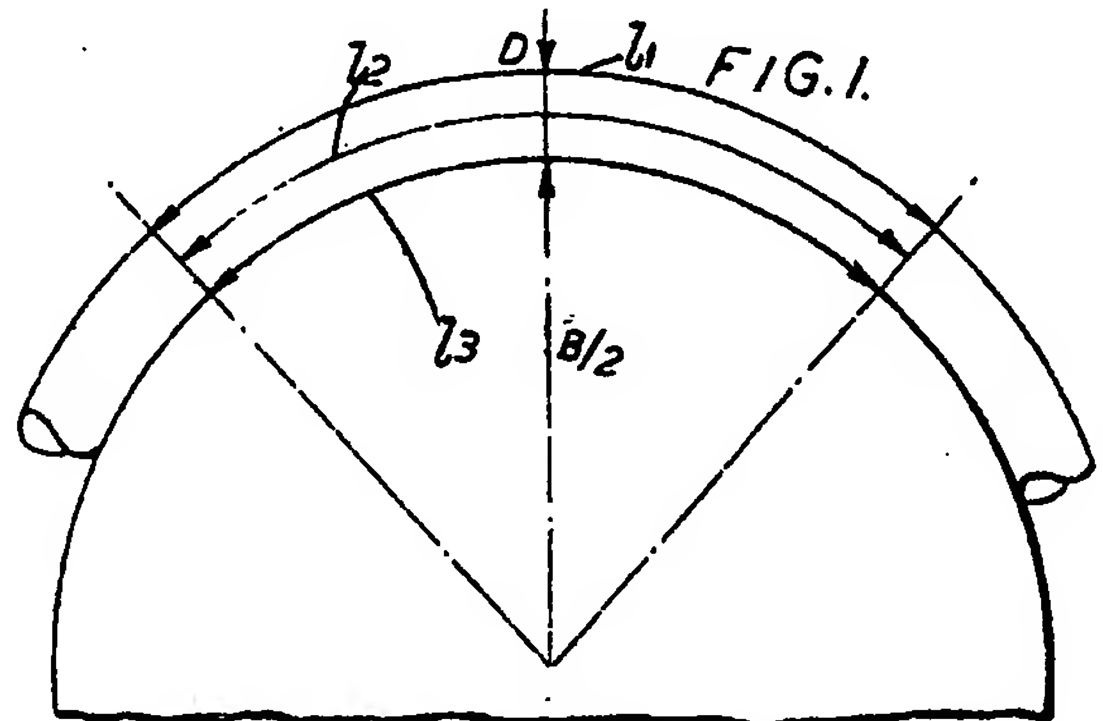

FIG.2.

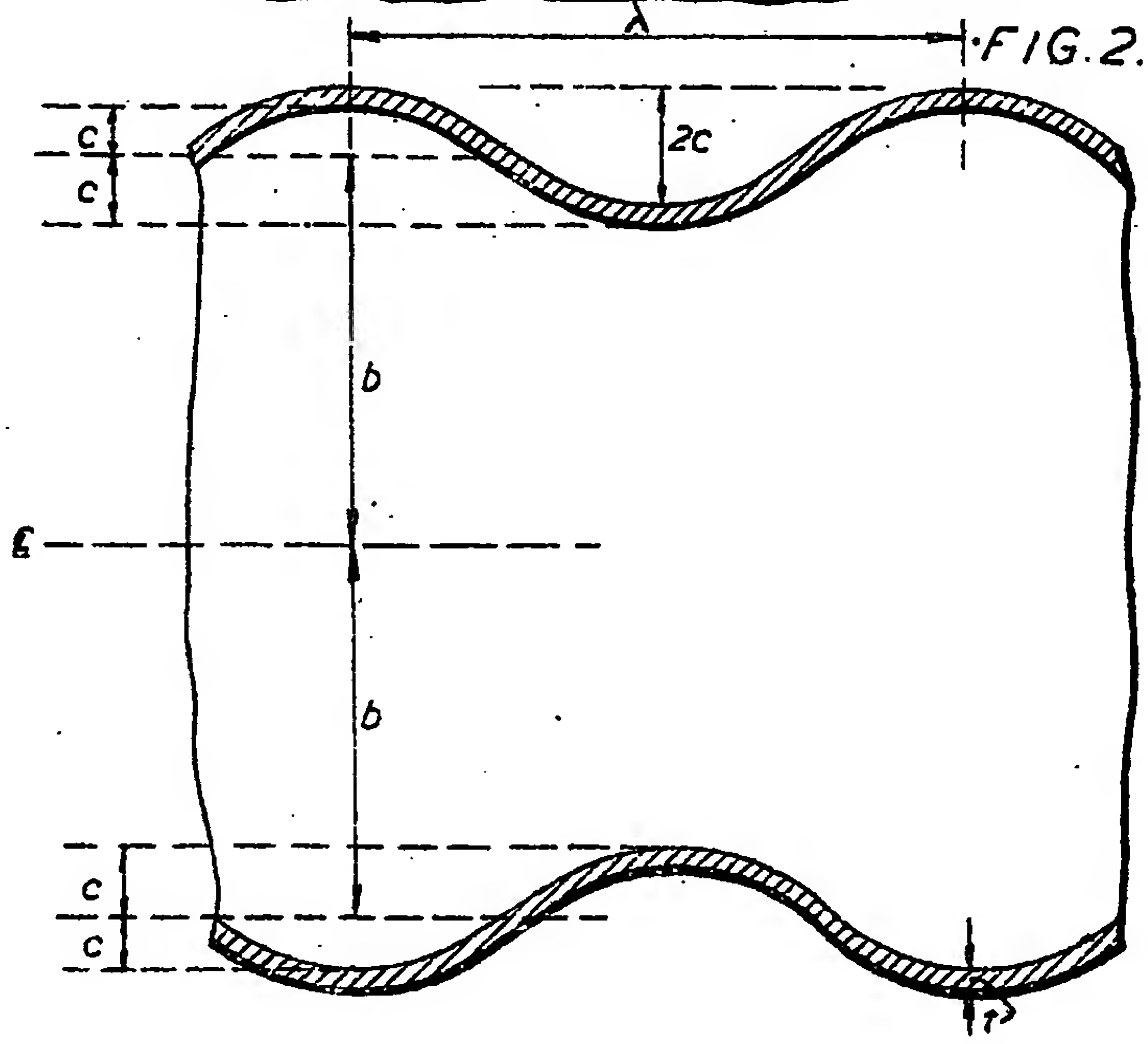

FIG.3.